# FUTURE DIRECTIONS OF THE NATIONAL CORS SYSTEM

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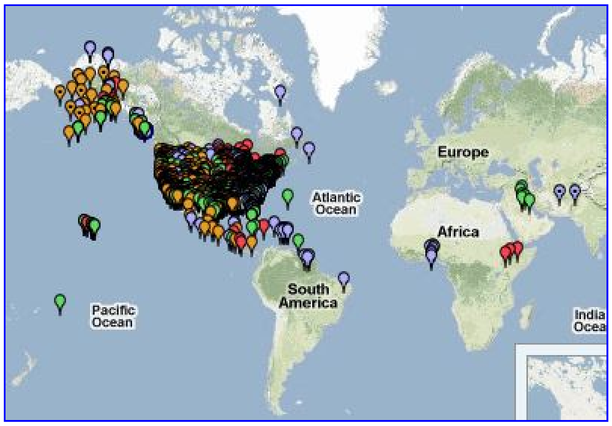


CORS COVERAGE MAP

## BIOGRAPHIES

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## INTRODUCTION

## ABSTRACT

The National Geodetic Survey (NGS) continues to enhance the National CORS (Continuously Operating Reference Station) system, thereby improving people's ability to apply Global Positioning System (GPS) data for positioning points with cm-level accuracy throughout the United States and its territories. People also use CORS data to develop geographic information systems, to monitor crustal deformation, to determine the distribution of water vapor in the atmosphere, to support remote sensing operations, and to determine the distribution of free electrons in the ionosphere. NGS is steadily increasing the spatial coverage of the National CORS system by adding an average of 3 new sites per month. In June 1999, the system contained 156 sites. In addition, NGS plans to regularly upgrade its user-friendly CORS information server, making CORS data and related information (descriptive text, site positions and velocities, GPS orbits, selected meteorological data, etc.) more readily available via the Internet. Also our agency is:

- generating digital models of antenna-phase-center variation, crustal motion, total electron content in the ionosphere, and geoid heights;
- supporting research to develop reduced multipath GPS sites; and
- investigating the possibility of providing nationwide digital maps of pertinent meteorological data for enabling more rigorous GPS processing.
  Moreover, NGS will continue to study how enhancements to the CORS system impact positioning accuracy and its relationship with the distance to the nearest CORS and the duration of an observing session.

> The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service, coordinates a network of Continuously Operating Reference Stations (CORS) that provide GPS carrier phase and code range measurements in support of 3-dimensional positioning activities throughout the United States and its territories.
>
> Surveyors, GIS/LIS professionals, engineers, scientists, and others can apply CORS data to position points at which other GPS data have been collected. When used in postsurvey mode, National CORS data enable positioning accuracies that approach a few centimeters relative to the National Spatial Reference System, both horizontally and vertically.

The National CORS system benefits from a multi-purpose cooperative endeavor involving many government, academic, commercial, and private organizations. New sites are evaluated for inclusion according to established criteria. As of June 1999, the system contained 156 sites, and it is currently growing at a rate of approximately 3 sites per month. This growth is expected to continue over at least the next few years, as the U.S. Department of Transportation is installing about 65 additional CORS as part of the Nationwide Differential GPS (NDGPS) service. In addition to serving as CORS, these NDGPS sites will broadcast "correctors" to the GPS signal, which enable navigation and real-time positioning at the few meter level. Also, NOAA's Forecast System Laboratory is utilizing existing and future NDGPS/CORS sites equipped with surface meteorological (Sfc. Met) sensors, and installing approximately 40 of its own CORS, to evaluate the impact of precipitable water vapor data derived from GPS signal delays on weather forecast accuracy. Finally, government agencies at all levels, academic institutions, and other organizations are installing additional GPS base stations for various other applications. Many of these are expected to join the National CORS system.

Data from all CORS are transmitted hourly or daily to NGS headquarters in Silver Spring, MD where these data are converted into RINEX (version 2) format and made publically available via the Internet. In particular, people may download CORS data either via anonymous ftp (file transfer protocol) using the address ftp://www.ngs.noaa.gov/cors/ or through the World Wide Web using the address http://www.ngs.noaa.gov/CORS/. Furthermore, people may pose CORS-related questions to NGS here.

**CORS INFORMATION SERVER**

In November 1998, NGS introduced a web-based utility to provide CORS users with customized datasets. Known as UFCORS, this user-friendly CORS information server is designed to save people from tedious data manipulation and file management tasks. In particular, UFCORS allows people to:

- request CORS data for an exact time interval specified in international or local time,
- choose a sampling rate for the requested data, and
- specify how the data should be compressed to speed data transfer to the user.

NGS plans to regularly upgrade UFCORS. During the summer of 1999 the agency will release a new version that will allow people to:

- receive the requested information within a few minutes,
- obtain pertinent descriptive text (log files and data sheets) for CORS sites,
- retrieve adopted NAD 83 and ITRF positions and velocities for CORS sites,
- obtain meteorological data for those CORS that have Sfc. Met sensors, and
- retrieve both the highly accurate GPS satellite orbits produced by the International GPS Service (IGS) and the "broadcast" GPS orbits.

A future version of UFCORS will feature an interactive map of the CORS network with links to pertinent information about these sites and their data so that people may easily identify the CORS data most suitable for their needs.

**DIGITAL MODELS**

To obtain extremely accurate positions, GPS users need various auxiliary sources of information, as embodied in digital models for antenna-phase-center variation, crustal motion, "space weather", and geoid heights. In each case, NGS is striving to provide people with the most accurate models available.

For modeling antenna-phase-center variation, NGS has calibrated several copies of each geodetic-quality antenna type. The resulting model for a particular antenna type describes how the location where the antenna receives incoming GPS signals varies as a function of the frequency of the signal and the elevation angle to the corresponding GPS satellite. Models for about 60 antenna types may be found at the web site http://geodesy.noaa.gov/ANTCAL/ .

Failure to account for antenna-phase-center variation can lead to errors of up to 10 cm in height when processing GPS data for a baseline involving two different antenna types.

For crustal motion, NGS has incorporated models derived by various researchers into a software package called HTDP (Horizontal Time-Dependent Positioning) [Snay, 1999]. This software may be used to predict velocities at any location in the United States as needed to relate positions derived for different times. In the coterminous United States, points typically move at speeds ranging between 10 and 20 mm/yr when referred to ITRF96 or to WGS 84 (G873). This motion, which is due to plate tectonics, is generally not a factor when points are referred to NAD 83. For all three of these reference frames, however, significant motions occur in California, Oregon, Washington, Alaska, and Hawaii. Recently, NGS created a web page which enables people to use HTDP interactively to predict velocities for individual points. People may access this page from http://www.ngs.noaa.gov by clicking on "Geodetic Tool Kit" and then clicking on "HTDP".

The ionosphere is a level of the upper atmosphere where a significant number of electrons have been removed from atoms and molecules to form free electrons and positively charged ions. Such ionization is commonly caused, for instance, by extreme ultraviolet light from the sun separating a single electron from an oxygen atom. The level of ionization varies as a function of both time and location; hence, the term "space weather" has been applied to this phenomenon.

The presence of free electrons in the ionosphere slows the speed of GPS radio signals traveling through it in a manner that is frequency dependent. As a consequence, the known differential effect on the two GPS frequencies can be used to monitor the total electron content of the ionosphere. Indeed, NGS scientists are using data from the National CORS system to construct contour maps of total electron content over the coterminous United States every 30 minutes. This quantity is routinely used to monitor ionospheric disturbances caused by geomagnetic storms and is a component of space weather forecasts and warnings.

Each contour map displays total electron content (TEC) as a function of geographic location for a given time. TEC (measured in units of $10^{16}$ electrons per $m^2$) quantifies the number of electrons for a given line of sight. Thus, the plotted TEC values are associated with vertical lines of sight from terrestrial points.

NGS plans to provide digital models corresponding to these maps so that people who use single frequency GPS receivers may apply appropriate corrections to their data.

GPS data can be readily processed to obtain ellipsoidal height, $h$, the height above or below a simple ellipsoid model of the Earth. Geodetic leveling, however, gives rise to orthometric height, $H$, often known as the height above or below mean sea level. Orthometric heights are found on topographic maps as well as stored in innumerable digital and paper datasets as they govern how water flows. To transform between these height systems, one requires the geoid height, $N$, to apply the equation: $h = H + N$. In and around the coterminous United States, geoid heights range from a low of -51.6 meters in the Atlantic Ocean to a high of -7.2 meters in the Rocky Mountains. NGS provides a high-resolution model, called GEOID96, for determining geoid heights and other geoid-related products [Smith and Milbert, 1999]. For details, see the web site http://www.ngs.noaa.gov/GEOID/ .

The agency expects to release an improved model, GEOID99, sometime in the fall of 1999.

**REDUCING MULTIPATH**

NGS' Geosciences Research Division is planning to explore the suppression of multipath effects on GPS signals through the use of an absorbing plane under the antenna. The plane will consist of commercially available non-reflecting material arranged in about an 8-foot square around the antenna. The edge of the material will be tapered to provide an impedance match to the surrounding surface and thereby reduce reflection's other edge effects. NGS plans to use differential phase measurements between antennas with and without the absorbing medium to explore the effectiveness of the absorbing plane.

Experiments with absorbing planes have been done in the past, but the results have not been published and are therefore difficult to evaluate. NGS intends to find out whether the performance of modern choke-ring type antennas and others can be significantly enhanced with these techniques. NGS also plans to investigate the effectiveness of various different types of absorbing media. The agency will evaluate whether these techniques can be made portable and suitable for field use, or suitable for permanent fixed stations, or will remain a largely experimental technique.

**WEATHER DATA**

A significant obstacle to obtaining accurate GPS results is due to refraction of the GPS signal by water vapor in the atmosphere. Most of the water vapor is located in the electrically neutral region of the lower atmosphere called the troposphere where most of the "weather" occurs. If unaccounted for, total tropospheric refraction, which has a wet and dry component, can delay the GPS signal by about 2.5 meters at sea level for a satellite at zenith. Bevis and others [1992] showed that the wet component of the zenith delay (ZWD) is nearly proportional to the total quantity of precipitable water vapor (PWV) in a column of air directly above the GPS antenna. As a rule of thumb,

$$ZWD \sim 6.4\ PWV\ .$$

NOAA weather prediction models provide reasonably accurate descriptions of the temperature, pressure, and moisture fields over the coterminous United States every hour, with predictions out to 3 and 12 hours. NGS intends to supply relevant atmospheric data to GPS users, distinguishing between observation analyses and forecasts, to enable users to compute more accurate positions in near real-time.

**ACCURACY VERSUS LENGTH & TIME**

NGS is studying how GPS positioning accuracy depends on the distance to the nearest CORS site and on the length of time of the observing session. Several GPS datasets were processed for 11 baselines distributed around the United States with baseline lengths ranging from 26 km to 300 km. Moreover, observing times ranged from 4 to 24 hours. Additional tests are now being performed for shorter observing times. Preliminary results indicate that:

- the effect of baseline length on positioning accuracy is negligible if "precise" GPS orbits are used, and
- the following table presents derived relationships between positioning accuracy (at the 2-sigma level) and observing time

| **Observing time (hours)** | **4** | **6** | **8** | **12** | **24** |
|---|---|---|---|---|---|
| North error (mm) | 10 | 8 | 6 | 5 | 3 |
| East error (mm) | 10 | 7 | 6 | 6 | 4 |
| Vertical error (mm) | 36 | 29 | 27 | 21 | 16 |

A more comprehensive report describing these results is in preparation.

**COMMENTS**

The National CORS system is rapidly becoming the preferred method for accurate 3D positioning in the United States. Unlike traditional geodetic control points, users need not set up instruments at the CORS; they need only to download pertinent data via the Internet. The web-based utility, UFCORS, has made such downloads easy. Although distances to CORS currently seem excessive, this disadvantage may be negated by using "precise" GPS orbits. As part of the CORS project, NGS is working with scientists around the world to develop digital models and techniques that will enable GPS users to determine accurate positions economically and in a timely manner.

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